Use of CC Traps with Different Trap Base Colors for Silverleaf Whiteflies (Homoptera: Aleyrodidae), Thrips (Thysanoptera: Thripidae), and Leafhoppers (Homoptera: Cicadellidae)

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J. Econ. Entomol. 93(4): 1329–1337 (2000)

ABSTRACT During 1996, 1997, and 1999, studies were conducted in cotton, sugar beets, alfalfa, yardlong bean, and peanut fields to compare insect catches in CC traps equipped with different trap base colors. The studies were conducted in southwestern United States, China, and India. The nine colors, white, rum, red, yellow, lime green, spring green, woodland green (dark green), true blue, and black, varied in spectral reflectance in the visible (400–700 nm) and near-infrared (700–1050 nm) portions of spectrum. Lime green, yellow, and spring green were the three most attractive trap base colors for silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring, and leafhopper, *Empoasca* spp. adults. The three trap base colors were moderately high in the green, yellow, and orange spectral regions (490–600 nm), resembling the spectral reflectance curve of the abaxial (underleaf) surfaces of green cotton leaves. True blue and white were the most attractive trap base colors for western flower thrips, *Frankliniella occidentalis* (Pergande), adults. The true blue and white trap bases were moderately high in the blue spectral region (400–480 nm).

KEY WORDS *Bemisia argentifolii, Empoasca* spp., *Frankliniella occidentalis,* CC traps, trap base reflectance

COLOR ATTRACTION IS an innate characteristic of insects. It is well known that yellow is attractive to whiteflies, *Asterochiton vaporarorium* Westwood (Lloyd 1921) and *Bemisia* spp. (Mound 1962); olive fruit flies, *Dacus oleae* Gmelin (Economopoulos 1986); western yellowjacket, *Vespula pensylvanica* (Saussure) (Chang 1988); and whitefly parasitoids *Eretmocerus* spp. (Hoelmer et al. 1998). Other insect species attracted to yellow are bumblebees, *Bombus* spp. (Gross and Carpenter 1991); corn flea beetles, *Chaetocnema publicaria* Melsheimer (Adams and Los 1986); vegetable leafminer, *Liriomyza sativae* Blanchard (Affeldt et al. 1983); western flower thrips, *Frankliniella occidentalis* (Pergrande) (Cho et al. 1995); and cereal aphids spp. (De Barro 1991). Gaum and Giliomee (1994) reported that greenhouse whiteflies, *Trialeurodes vaporariorum* (Westwood), responded more positively to yellow with a peak reflectance at 600 nm. Western flower thrips, in contrast, showed a greater phototactic response to bright blue sticky traps with a peak reflectance at 460 nm. Blackmer et al. (1995) reported that 76% of *Bemisia tabaci* (Gennadius) adults responded to a visual wavelength stimulus at 550 nm in a flight chamber. Numerous other reports also indicate that thrips are attracted to blue as well as white (Yudin et al. 1987, Matteson and Terry 1992, Brodsgaard 1993). Vernon and Gillespie (1995) found that yellow colored traps placed in front of violet or blue backgrounds caught significantly more thrips than yellow colored traps in front of yellow backgrounds.

A new whitefly trap (CC trap, Fig. 1) was developed recently and patented in United States for monitoring silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring, activity in cotton and other field crops (Chu and Henneberry 1998, Chu et al. 1998a). The design of the trap was based on silverleaf whitefly adult behavior including attraction to yellow color (Mound 1962, Byrne et al. 1986), movement of adults for feeding and oviposition to shaded underleaf surfaces (Chu et al. 1995), and orientation to light when leaving host leaves (Chu et al. 1998b). The trap consists of three components: a clear plastic trap top to admit light for adult orientation into the trap, a deflector plate to reduce the escape of trapped adults, and a yellow colored trap base with an opening for adult entrance (Chu and Henneberry 1998). No sticky materials, pheromones, or baits are included. In trap evaluation studies, catches of silverleaf whitefly adults were significantly correlated with catches on yellow sticky card traps (Chu and Henneberry 1998, Hoelmer et al.

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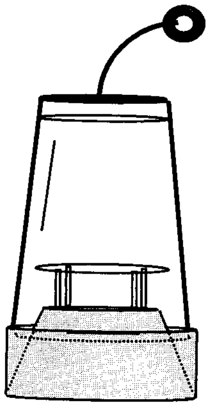

Fig. 1. CC trap.

1998). The trap was adopted in 1996 by the Imperial County Agricultural Commissioner's Office, El Centro, CA, for monitoring whitefly populations (Ritter et al. 1997). Recent studies showed that the CC trap catches were highly correlated to leaf-turn treatments of the method of adult whitefly sampling (Chu et al. 1998a).

The objective of the current studies was to determine the effect of different colored trap bases on whitefly catches. We also explored the potential use of the trap for catching thrips and leafhoppers and measured the spectral reflectance characteristics of the different trap color bases for consideration in relation to attractant qualities.

Materials and Methods

Nine trap studies were conducted in the field to investigate the effects of different trap base colors on catches of silverleaf whiteflies, thrips spp., and leafhopper spp. The studies were conducted in the United States (California and Arizona), India, and the People's Republic of China in 1996, 1997, and 1999. The trap studies were conducted in cotton, *Gossypium hirsutum* L.; alfalfa, *Medicago sativa* L.; sugarbeets, *Beta vulgaris* L.; yardlong bean, *Vigna sesquipedalis* L.; and peanut, *Arachis hypogaea* L.

California and Arizona Silverleaf Whiteflies, Western Flower Thrips, and Leafhopper spp.—Cotton. Experiments 1 and 2 were choice tests conducted in a cotton field at the USDA-ARS Irrigated Desert Research Station, Brawley, CA, Deltapine '5461' cotton seed was planted on 12 March 1996 and 22 April 1997. The experimental designs were randomized complete blocks with 10 replicates for both years. In 1996 (experiment 1), each plot was 12 rows wide and 30 m long. Rows were spaced 1 m apart. Five different traps with a white, rum, yellow, spring green, or true blue trap base were tied to wire loops 7 cm apart on a movable horizontal bar attached to a 165 cm high vertical stake. Traps on stakes were installed in the center of plots between two center rows as described in a previous report (Chu et al. 1998a). Trap heights from the ground were adjusted relative to the growth of plants to maintain the trap bases at levels of 15 cm below the canopy top. Traps were exposed, in each case, for 24 h on each of 19 sampling dates from 5 June to 6 August. After each exposure, traps with insects were frozen, poured out, and counted. In the 1997 (experiment 2) choice test, each cotton plot was eight rows wide and 20 m long. Rows were 1 m apart. For experiments 2 through 8, the rum trap base color was eliminated and red, lime green, dark green, and black trap base colors were added. The traps in experiment 2 were exposed for 24 h on each of nine sampling dates from 29 April to 27 May.

Experiment 3 was a choice test conducted in 1997 at Maricopa, AZ. Cotton Deltapine '5415' was planted on 15 April. The experimental design was a randomized complete block with 10 replicates. Each plot was eight rows wide and 15 m long. Rows were spaced 1 m apart. Traps were placed 15 cm below the canopy top and were exposed, in each case, for 24 h on 10 sampling dates from 17 July to 17 September.

Experiment 4 was a choice test and experiment 5 was a no-choice test; each experiment was conducted in 1999 at Maricopa, AZ. Cotton, 'NuCOTN 33B' (a bio-engineered cultivar similar to Deltapine 5415) for both experiments was planted on 17 April. The design of each experiment was a randomized complete block with eight replicates. Each plot was six rows wide and 15 m long. Rows were spaced 1 m apart. Traps were placed 15 cm below cotton canopy, one trap (one color) on each individual stake for the no-choice study was installed in the center of each plot. The trap arrangement for the choice test was identical to that described for experiments 1 and 2. Traps in both experiments in the 1999 studies were exposed for seven sampling dates during the period from 5 August to 15 September.

Alfalfa and Sugarbeets. Experiments 6 and 7 were choice tests conducted in 1997 at the USDA-ARS Irrigated Desert Research Station at Brawley, CA, and the University of California Desert Research and Extension Center, Holtville, CA, respectively. Experiment 6 was conducted in an alfalfa cultivar '100' field planted in 1993. Plots were 17 m wide and 150 m long. The experiment design was a randomized complete block with 10 replicates. Traps were placed in the middle of plots, with the trap bases 2–4 cm above the top of plant canopy. This trap height was based on earlier results indicating less variable whitefly trap catches between traps and leaf-turn counts for short plant height crops (Chu et al. 1998c). Traps were placed in the field 1 wk before the next green cut (harvest) and exposed for 24 h on each occasion for 13 sampling dates from 16 April to 4 June.

Experiment 7 was conducted in a sugarbeet cultivar '9S-781R' field planted on 30 September 1996. The experimental design was a randomized complete block with 10 replicates. Trap bases were placed 10 cm below the top of plant canopies. Traps were exposed for 24 h on each occasion for 13 sampling dates from 5 March to 22 April. 1997.

Table 1. Seasonal mean numbers of *Bemisia argentifolii* adults caught in cotton with CC traps with different color trap bases, Brawley, CA, and Maricopa, AZ, 1996 and 1997

Experiment no.	Crop/location	Monitoring period	Trap base color	No./trap/day ± SEM (% of yellow color)
1	Cotton, Brawley, CA	5 June–6 Aug.	White	28.3 ± 1.8c (36)
			Rum	24.3 ± 1.9c (31)
			Yellow	78.4 ± 6.2a (100)
			Spring green	48.5 ± 2.8b (62)
			True blue	14.6 ± 1.6d (19)
F, df				83.2; 4, 36
2	Cotton, Brawley, CA	29 April–27 May	White	3.2 ± 0.4c (47)
			Red	1.6 ± 0.2de (24)
			Yellow	6.8 ± 0.7b (100)
			Lime green	10.3 ± 1.0a (151)
			Spring green	7.2 ± 0.8b (106)
			Dark green	2.7 ± 0.4cd (40)
			True blue	0.8 ± 0.1e (12)
			Black	1.6 ± 0.2de (24)
F, df				66.5; 7, 63
3	Cotton, Maricopa, AZ	17 July–17 Sept.	White	57.6 ± 8.4c (43)
			Red	36.6 ± 5.2d (27)
			Yellow	133.1 ± 8.9b (100)
			Lime green	152.6 ± 12.1a (115)
			Spring green	115.0 ± 11.0b (86)
			Dark green	36.4 ± 4.6d (27)
			True blue	24.3 ± 2.5d (18)
			Black	30.9 ± 5.0e (23)
F, df				58.1; 7, 63

Means ± SEM in a column of a crop followed by the same letters are not significantly different (Student–Neuman–Keul multiple range test, $P = 0.05$).

China and India Thrips and Leafhopper spp.—Yardlong Bean. Experiment 8 was a no-choice test conducted in a 0.05-ha yardlong bean field in Nanning, Guangxi, the Peoples' Republic of China. Three seeds per hill were planted on 26 July 1997 and spaced 30 cm in a row. There were 32 rows in the field with a row spacing of 50 cm. The field was divided into 16 plots, each plot was four rows wide and 15 m long. The study was initiated when trellised plants were ≈180 cm high. The experimental design was a randomized complete block with two replicates. Traps were hung on the trellises in the middle of plots with trap bases 15 cm below the top of plants. Traps were exposed for 24 h on each of 27 sampling dates from 29 September to 27 October 1997. Insects caught in traps were killed by drowning in water. The different insect species caught were separated and counted.

Peanut. Experiment 9 was a no-choice test conducted in a 0.15-ha peanut, 'CVJL24' field planted on 21 June 1997 in Rajendranagar, Andhra Pradesh, India. The trap study was initiated when thrips activity, based on previous experience, was expected to be the highest during the season. The experiment was conducted in a completely randomized design with six replicates. Each plot was ≈20 by 20 m. Trap base colors were white, yellow, and green. Each trap was hung on a stake with trap bases placed 10 cm above the crop canopy. Traps were retrieved after 24-h exposures each week for 8 wk from 2 July to 26 August 1997. Live thrips were counted after each trap retrieval.

Reflectance Characteristics of Different Color Trap Bases. The nine trap base colors were those described in the Monsanto (Monsanto 1993) color chart as white, rum, red, yellow, lime green, spring green, woodland green (dark green), true blue, and black. A Personal Spectrometer II (PSII, Analytical Spectral Devices, Boulder, CO) was used to obtain color spectral data from trap bases that were illuminated by midday, direct beam sunlight, and diffuse sky irradiance. The spectrometer has a nominal 350- to 1,050-nm spectral response, 1.4-nm sampling interval, and ≈3-nm spectral resolution. Fiber optics of the spectrometer were equipped with 10° field-of-view. Measurements were made with the sensor oriented normal (perpendicular) to the outside surface of the trap bases. Reflectance factors were computed as the ratio of trap base radiances to irradiances estimated from frequent PSII measurements over a calibrated, $BaSO_4$ reference panel. Reflectance of field-grown cotton leaves was used as a reference for comparison with colored trap bases.

Data Analyses. Numbers of insects trapped for each experiment were analyzed using analysis of variance for each experimental design. Data transformation were performed using square root plus one whenever a heterogeneous data set was found (Anonymous 1989). Seasonal means are compared with mean separations obtained using the Student–Neuman–Keul multiple range test.

Results

California and Arizona Silverleaf Whiteflies—Cotton. In cotton during 1996 at Brawley, CA (experiment 1), traps with yellow color bases caught an average of 78.4 adult whiteflies per trap per day over a period of 19 wk from 5 June to 6 August 1996, compared with 48.5 adult whiteflies per trap per day caught with traps

Table 2. Mean and seasonal mean numbers of *Bemisia argentifolii* adults caught in choice and no-choice tests in cotton with CC traps with different color trap bases, Maricopa, AZ, 1999

Sampling date	No./trap/day ± SEM								
	Trap base color								
	Black	Blue	Dark green	Spring green	Lime green	Yellow	Red	White	*F*
				Experiment 6 choice test					
August									
5	7.0 ± 1.6c	6.4 ± 1.0c	10.1 ± 2.1c	23.3 ± 2.6b	42.3 ± 7.1a	47.8 ± 7.4a	6.0 ± 1.5c	10.3 ± 1.5c	29.8
11	11.3 ± 1.6c	17.8 ± 3.1c	21.9 ± 2.2c	52.9 ± 11.7b	107.9 ± 12.1a	88.0 ± 14.8a	14.9 ± 2.2c	20.0 ± 2.5	29.0
18	49.0 ± 10.5c	36.9 ± 9.5c	45.9 ± 8.6c	97.9 ± 13.0b	225.5 ± 20.3a	252.9 ± 11.5a	35.0 ± 4.2c	49.9 ± 5.0c	60.9
24	21.9 ± 2.4cd	20.6 ± 4.6cd	22.1 ± 3.1cd	36.8 ± 2.6c	71.4 ± 12.8b	100.6 ± 11.1a	13.5 ± 2.4d	25.5 ± 2.2cd	24.8
September									
1	13.9 ± 2.1bc	10.0 ± 1.8c	14.6 ± 2.4bc	22.0 ± 2.9b	81.4 ± 7.4a	95.4 ± 9.8a	13.5 ± 2.9bc	20.9 ± 3.2b	82.9
8	14.4 ± 2.3c	17.6 ± 2.7c	8.5 ± 2.2c	37.6 ± 10.1b	78.8 ± 9.4a	97.0 ± 14.0a	11.6 ± 2.6c	18.0 ± 4.0c	26.8
15	70.8 ± 13.3b	44.3 ± 7.5b	71.8 ± 14.7b	122.3 ± 13.8a	143.4 ± 13.4a	175.5 ± 22.9a	75.3 ± 11.8b	58.8 ± 13.8b	13.5
Seasonal mean	26.9 ± 2.3D	21.9 ± 2.5D	27.8 ± 2.5D	56.8 ± 5.2C	107.2 ± 7.3B	122.4 ± 5.3A	24.3 ± 1.5D	29.0 ± 2.3D	115.3
				Experiment 7 no-choice test					
August									
5	13.6 ± 8.2b	8.1 ± 1.3b	7.6 ± 1.0b	21.3 ± 3.7b	43.8 ± 7.3a	50.9 ± 13.9a	5.8 ± 0.7b	9.0 ± 2.6b	9.9
11	10.0 ± 1.1c	15.0 ± 2.8c	10.8 ± 1.7c	48.0 ± 13.4b	78.9 ± 8.0a	98.3 ± 13.3a	13.0 ± 1.5c	24.4 ± 5.0c	27.3
18	26.4 ± 2.3c	33.5 ± 4.4c	36.9 ± 4.9c	86.6 ± 12.8b	193.0 ± 26.7a	242.3 ± 28.6a	40.5 ± 6.1c	42.6 ± 5.7c	42.5
24	20.6 ± 3.5b	24.0 ± 7.5b	16.3 ± 1.6b	26.8 ± 2.8b	59.1 ± 7.1a	74.9 ± 13.1a	22.0 ± 4.6b	19.6 ± 4.9b	14.3
September									
1	13.0 ± 1.7c	13.3 ± 3.2c	16.8 ± 3.0bc	21.4 ± 2.1b	66.5 ± 6.4a	82.5 ± 9.7a	11.8 ± 1.5c	16.3 ± 3.9bc	40.8
8	6.5 ± 1.5c	8.9 ± 2.6c	17.3 ± 2.4b	13.6 ± 2.3bc	49.6 ± 4.9a	54.9 ± 7.4a	8.6 ± 2.1c	13.4 ± 3.0bc	2.9
15	57.5 ± 5.5b	47.6 ± 7.5b	64.1 ± 8.2b	65.1 ± 11.6b	167.3 ± 11.1a	138.0 ± 16.3a	73.3 ± 9.1b	66.0 ± 11.1b	11.9
Seasonal mean	21.1 ± 1.8D	21.5 ± 1.6D	24.2 ± 1.1D	40.4 ± 2.9C	94.0 ± 4.3B	105.9 ± 4.4A	25.0 ± 2.3D	27.3 ± 2.9D	148.1

Means ± SEM in a row of a sampling date followed by the same (lowercase or capital) letters are not significantly different (Student–Neuman–Keul multiple range test, $P = 0.05$). Degrees of freedom are 7, 49 for treatment and error, respectively, for each sampling date and seasonal means.

with spring green color bases (Table 1). Traps with spring green color bases caught about twice as many whiteflies compared with white or rum color bases. Of the five trap base colors, traps with true blue color bases caught the fewest number of whitefly adults. In 1997 at Brawley, CA (experiment 2), traps with lime green color bases caught an average of 10.3 adult whiteflies per trap per day from 29 April to 27 May (in early cotton season), compared with 6.8 adult whiteflies per trap per day caught with the traps with yellow color bases. Catches in traps with spring green bases were similar to catches in traps with yellow color bases. Traps with white, red, dark green, true blue, or black bases caught significantly fewer adult whiteflies compared with traps with lime green, yellow, or spring green bases. At Maricopa, AZ (experiment 3), from 17 July to 17 September 1997, traps with lime green color bases caught an average of 152.6 adult whiteflies per trap per day, 15% more than traps with yellow color bases. Traps with spring green bases caught similar numbers of adults as those with yellow bases. Significantly fewer adult whiteflies were caught in traps with other color bases compared with lime green, yellow, and spring green bases.

For experiments 4 (choice test) and 5 (no-choice test), seasonal mean numbers and mean numbers for individual sampling dates, in most cases, were highest in traps with yellow bases, followed by traps with lime green color and spring green color bases. Significantly fewer whiteflies were caught in traps with white, dark green, black, red, and blue in both choice and no-choice tests (Table 2). On six of the seven sampling dates, numbers caught in the traps with yellow and lime green bases were not significantly different. The trap catch relationships between choice (X) and no-choice (Y) trap arrangements were significant ($Y = 0.61 + 0.85 \times$ and $Y = 10.52 + 0.98X$, $r^2 = 0.99$ and $n = 8$).

Alfalfa and Sugarbeets. In the alfalfa field in 1997 (experiment 6), 1.5 and 1.3 whiteflies per trap per day were caught from 16 April to 4 June in traps with yellow or lime green bases, respectively, compared with <1 (0.1–0.5) adults per trap per day in other traps. These data are not tabulated nor are the results of catches in sugarbeet fields at Holtville, CA (experiment 7), where average catches of <0.1 adult whitefly per trap per day occurred from 5 March to 22 April 1997.

California and Arizona Western Flower Thrips and Leafhopper spp.—Cotton. In cotton during 1997 at Brawley, CA (experiment 2), traps with white, yellow, and blue bases caught the highest numbers of adult thrips per trap per day, compared with catches in traps with other color bases (Table 3). At Maricopa, AZ, traps with blue bases (experiment 3) caught 4.5 adult thrips per trap per day, compared with 2.8 and 1.7 thrips in traps with white and yellow bases, respectively. Other traps caught less than one adult thrips per trap per day. In cotton during 1999 at Maricopa (experiments 6 and 7), mean numbers of thrips caught in both choice and no-choice tests were highest in traps with blue color bases, followed by traps with white bases (Table 4). Thrips catches in traps with black, dark green, spring green, lime green, yellow, or red

Table 3. Seasonal mean numbers of *Frankiniella occidentalis* and *Empoasca* spp. caught in cotton, alfalfa, and sugarbeets with CC traps with different color trap bases at Brawley and Holtville, CA, and Maricopa, AZ, 1996 and 1997

Experiment no.	Crop/location	Monitoring period	Trap base color	No./trap/day ± SEM	
				F. occidentalis (% of white color)	*Empoasca* Spp. (% of yellow color)
1	Cotton, Brawley, CA	5 June–6 Aug.	White	—	3.9 ± 0.5c (56)
			Rum	—	8.9 ± 1.0a (127)
			Yellow	—	7.0 ± 0.8b (100)
			Spring green	—	10.0 ± 1.1a (143)
			True blue	—	4.6 ± 0.6c (66)
F, df					33.0; 4, 36
2	Cotton, Brawley, CA	29 April–27 May	White	2.7 ± 0.4a (100)	4.3 ± 0.4d (46)
			Red	0.4 ± 0.1c (15)	6.4 ± 0.6c (69)
			Yellow	2.2 ± 0.3b (81)	9.3 ± 0.9a (100)
			Lime green	1.0 ± 0.1c (37)	7.7 ± 0.7b (83)
			Spring green	0.8 ± 0.1c (30)	8.4 ± 0.8ab (90)
			Dark green	0.6 ± 0.1c (22)	6.0 ± 0.6c (64)
			True blue	2.1 ± 0.2b (78)	3.5 ± 0.3d (38)
			Black	0.4 ± 0.1c (15)	4.5 ± 0.4d (48)
F, df				31.8; 7, 63	35.8; 7, 63
3	Cotton, Maricopa, AZ	17 July–17 Sept.	White	2.8 ± 0.4b (100)	0.8 ± 0.2b (24)
			Red	0.4 ± 0.1d (14)	0.6 ± 0.2b (18)
			Yellow	1.7 ± 0.3c (61)	3.3 ± 0.5a (100)
			Lime green	0.8 ± 0.2d (29)	3.1 ± 0.6a (94)
			Spring green	0.8 ± 0.2d (29)	3.1 ± 0.5a (94)
			Dark green	0.7 ± 0.2d (25)	1.0 ± 0.2b (30)
			True blue	4.5 ± 0.7a (161)	0.3 ± 0.1b (9)
			Black	0.8 ± 0.2d (29)	0.5 ± 0.1b (15)
F, df				12.5; 7, 63	15.9; 7, 63
4	Alfalfa, Brawley, CA	16 April–4 June	White	35.7 ± 4.0a (100)	0.5 ± 0.1b (45)
			Red	2.2 ± 0.3c (6)	0.4 ± 0.1b (36)
			Yellow	28.0 ± 3.6b (78)	1.1 ± 0.2a (100)
			Lime green	4.6 ± 0.3c (13)	1.1 ± 0.1a (100)
			Spring green	3.2 ± 0.5c (9)	1.1 ± 0.1a (91)
			Dark green	1.9 ± 0.1c (5)	0.4 ± 0.1b (36)
			True blue	33.9 ± 2.5a (95)	0.3 ± 0.1b (27)
			Black	1.6 ± 0.3c (4)	0.4 ± 0.1b (36)
F, df				61.2; 7, 63	64.1; 7, 63
5	Sugarbeet, Holtville, CA	5 Mar.–22 April	White	13.9 ± 2.1a (100)	1.0 ± 0.3d (17)
			Red	0.4 ± 0.1c (3)	1.3 ± 0.3d (22)
			Yellow	5.9 ± 0.8b (42)	5.8 ± 0.5a (100)
			Lime green	0.9 ± 0.1c (6)	4.9 ± 0.6b (84)
			Spring green	0.6 ± 0.1c (4)	4.0 ± 0.5c (69)
			Dark green	0.4 ± 0.1c (3)	0.9 ± 0.2d (16)
			True blue	8.5 ± 1.4b (61)	0.2 ± 0.1e (3)
			Black	0.3 ± 0.1c (2)	0.8 ± 0.2d (14)
F, df				37.1; 7, 63	7.6; 7, 63

Means ± SEM in a column of a crop followed by the same letters are not significantly different (Student–Neuman–Keul multiple range test, $P = 0.05$).

bases were not significantly different. On individual sampling dates, traps with blue bases caught the most thrips on six of the seven sampling dates.

In cotton during 1996 at Brawley, CA (experiment 1), traps with green and rum color bases caught an average of 10 and 8.9 adult leafhoppers per trap per day, respectively, compared with 7.0 in yellow color base traps (Table 3). Traps with blue and white color base traps caught the fewest numbers of leafhoppers. In cotton during 1997 at Brawley, CA (experiment 2), yellow, spring green, and lime green color base traps caught more adult leafhoppers compared with white, red, dark green, true blue, and black color base traps.

Alfalfa and Sugarbeets. In alfalfa at Brawley, CA, in 1997 (experiment 6), white, true blue, and yellow color base traps caught 35.7, 33.9, and 28.0 adult thrips per trap per day, respectively, compared with fewer than five thrips in traps with other trap base colors (Table 3). In sugarbeets at Holtville, CA (experiment 7), white color base traps caught 13.9 adult thrips per trap per day, compared with 8.5 and 5.9 adult thrips per trap per day, respectively, in true blue and yellow color base traps.

China and India Thrips and Leafhopper spp.—Yardlong Bean. In China (experiment 8), traps with true blue bases caught 22.8 adult western flower thrips per trap per day, compared with 12.2 in traps with white bases (Table 5). Traps with other color bases caught fewer than two adult thrips per trap per day. Adult leafhopper catches ranged from 3.6 to 5.7 adults per trap per day and there were no significant differences between traps with different color bases (Table 5).

Peanut. In India (experiment 9), traps with white color bases caught 39.8 adult *S. dorsalis* per trap per day, compared with 15.9 *S. dorsalis* per trap per day in

Table 4. Mean and seasonal mean numbers of *Frankiniella occidentalis* caught in choice and no-choice tests with CC traps with different color trap bases, Maricopa, AZ, 1999

Sampling date	No./trap/day ± SEM								
	Trap base color								
	Black	Blue	Dark green	Spring green	Lime green	Yellow	Red	White	*F*
	Experiment 4 choice test								
August									
5	3.0 ± 2.4b	24.9 ± 3.4a	1.3 ± 0.4b	1.6 ± 0.9b	0.6 ± 0.3b	11.6 ± 8.8b	1.3 ± 0.7b	7.8 ± 2.0b	9.7
11	0.6 ± 0.3b	8.5 ± 2.4a	1.0 ± 0.4b	1.7 ± 0.9b	1.3 ± 1.1b	1.1 ± 0.8b	1.3 ± 0.5b	3.3 ± 0.5b	6.5
18	1.3 ± 0.4c	10.6 ± 3.3a	1.4 ± 0.8c	0.6 ± 0.4c	2.1 ± 0.9bc	3.1 ± 1.4bc	1.3 ± 0.4c	5.1 ± 1.1b	7.3
24	0.8 ± 0.3c	11.6 ± 2.9a	0.4 ± 0.3c	1.3 ± 0.5c	0.6 ± 0.3c	1.3 ± 0.4c	1.0 ± 0.4c	4.9 ± 1.0b	13.3
September									
1	0.3 ± 0.2b	7.6 ± 1.7a	0.5 ± 0.2b	0.0 ± 0.0b	0.1 ± 0.1b	0.0 ± 0.0b	0.1 ± 0.1b	1.9 ± 0.7b	15.5
8	0.1 ± 0.1b	4.5 ± 0.9a	0.3 ± 0.2b	0.4 ± 0.3b	0.1 ± 0.1b	0.1 ± 0.1b	0.5 ± 0.2b	1.0 ± 0.4b	15.4
15	0.5 ± 0.3b	4.1 ± 1.1a	0.5 ± 0.4b	0.9 ± 0.4b	1.0 ± 0.4b	0.3 ± 0.2b	0.0 ± 0.0b	1.1 ± 0.3b	6.6
Seasonal mean	1.0 ± 0.4C	10.3 ± 1.2A	0.8 ± 0.2C	0.9 ± 0.2C	0.8 ± 0.3C	2.5 ± 1.3BC	0.8 ± 0.2C	3.6 ± 0.2B	22.9
	Experiment 5 no-choice test								
August									
5	1.8 ± 1.0c	41.4 ± 1.0a	0.1 ± 0.1c	0.5 ± 0.3c	3.1 ± 3.0c	2.4 ± 0.8c	0.9 ± 0.5c	10.4 ± 3.2b	19.7
11	1.4 ± 0.0c	9.3 ± 2.2a	0.0 ± 0.0c	0.1 ± 0.1c	5.1 ± 3.3bc	0.6 ± 0.3c	0.4 ± 0.3c	7.4 ± 2.7ab	6.6
18	0.4 ± 0.2c	8.9 ± 1.9a	1.0 ± 0.5c	0.4 ± 0.2c	0.8 ± 0.4c	1.8 ± 1.0c	0.8 ± 0.4c	5.8 ± 1.4b	12.9
24	1.4 ± 0.5b	4.1 ± 2.1ab	1.4 ± 0.7b	0.5 ± 0.4b	1.3 ± 0.7b	0.6 ± 0.4b	1.1 ± 0.5b	7.3 ± 2.2a	4.3
September									
1	1.5 ± 1.0ab	2.1 ± 1.1a	0.4 ± 0.3bc	0.3 ± 0.2bc	0.1 ± 0.1bc	0.8 ± 0.5abc	0.0 ± 0.0c	1.6 ± 0.5a	2.7
8	0.0 ± 0.0c	1.6 ± 0.6a	0.6 ± 0.4abc	0.5 ± 0.3bc	1.1 ± 0.5ab	0.5 ± 0.1bc	0.1 ± 0.1bc	1.6 ± 0.5a	2.6
15	1.6 ± 0.3a	1.8 ± 0.6a	0.5 ± 0.3a	0.8 ± 0.5a	0.3 ± 0.2a	0.8 ± 0.5a	0.3 ± 0.2a	1.5 ± 0.2a	2.1
Seasonal mean	1.1 ± 0.3C	9.9 ± 1.8A	0.6 ± 0.2C	0.45 ± 0.1C	1.7 ± 1.0C	1.1 ± 0.2C	0.5 ± 0.2C	5.1 ± 0.8B	17.3

Means ± SEM in a row of a sampling date followed by the same (lowercase or capital) letters are not significantly different (Student–Neuman–Keul multiple range test, $P = 0.05$). Degrees of freedom are 7, 49 for treatment and error, respectively, for each sampling date and seasonal means.

traps with yellow bases (Table 5). Traps with spring green bases caught the fewest number of *S. dorsalis.* Traps with white bases also caught more *Thrips palmi* Karny adults compared with traps with yellow bases.

Reflectance Characteristics of Difference Color Trap Bases. The different colored plastic trap bases had spectral reflectance characteristics that varied markedly over the visible (400–700 nm) and near-infrared (700–1050 nm) portions of the spectrum (Fig. 2A and B). The different spectral shapes appear to be associated with numbers of whiteflies, thrips, and leafhoppers caught. The three most attractive trap base colors for whiteflies and leafhoppers were lime green, spring green, and yellow (Fig. 2A). Their reflectances were relatively low in the blue spectral regions (400–460 nm) and moderately high in the green, yellow, and orange spectral regions (490–600 nm). Both the lime green and spring green colored trap bases differed considerably from the yellow colored trap base and the commercially available, yellow sticky card traps (not shown in figures) by having rather low reflectances in the red (600–700 nm) and red to near-infared transition spectral region (700–740 nm). It is relevant to note that (abaxial) underleaf surfaces of healthy green cotton leaves (Fig. 2A) displayed a peak at 550 nm that was similar to the 520 nm peaks mea-

Table 5. Mean numbers of *Frankiniella occidentalis* and *Empoasca* spp. caught in yardlong bean, and *Scirtothrips dorsalis* and *Thrips palmi* in peanut with CC traps with different color bases in Nanning, Guangxi, Peoples' Republic China (experiment 8) and Patancheru, Andhra Pradesh, India (experiment 9), respectively, 1997

Trap base color	No./trap/day ± SEM (% of white color)			
	China, 29 Sept.–27 Oct.		India, 2 July–26 Aug.	
	F. occidentalis	*Empoasca* spp.	*S. dorsalis*	*T. palmi*
White	12.2 ± 2.0b (100)	4.4 ± 0.9a (110)	38.8 ± 5.0a (100)	17.3 ± 0.9a (100)
Red	1.7 ± 0.6c (14)	4.8 ± 0.9a (120)	—	—
Yellow	0.3 ± 0.1c (2)	4.0 ± 1.3a (100)	15.9 ± 1.0b (40)	11.0 ± 12.0b (64)
Lime green	0.6 ± 0.2c (5)	3.6 ± 0.6a (90)	—	—
Spring green	0.3 ± 0.1c (2)	4.6 ± 1.0a (115)	4.4 ± 0.6c	—
Dark green	0.2 ± 0.1c (2)	4.5 ± 0.7a (112)	—	—
True blue	22.8 ± 2.7a (187)	5.7 ± 0.8a (142)	—	—
Black	0.1 ± 0.1c (1)	4.8 ± 0.7a (120)	—	—
F, df	17.4; 1, 7	0.2; 7, 7	31.0; 2, 21	27.0; 1, 14

Means in a column of a crop with different followed by the same letters are not significantly different (Student–Neuman–Keul multiple range test, $P = 0.05$). —, No data.

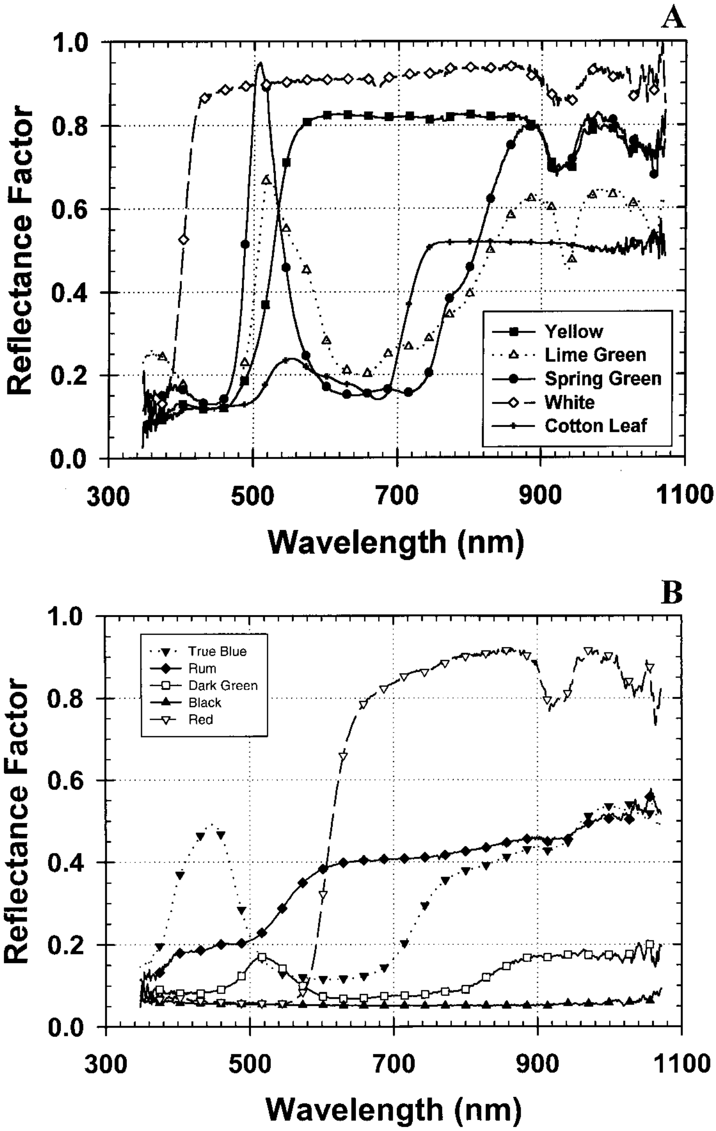

Fig. 2. Spectral reflectance of CC trap base colors, yellow, lime green, spring green, white in reference to underleaf surface of cotton leaves (A), and true blue, rum dark green, black and red (B).

sured on the lime green and spring green trap base, respectively. The yellow trap base did not have a prominent peak in the green region (500–550 nm) but displayed a high reflectance beginning from 580 nm and upward. By comparison, the normal green cotton leaves also displayed low blue and red reflectances, a small peak in the green and yellow green, and high near-infared reflectances and thus resembled the lime green and spring green trap base spectral curves in overall shape. The least attractive trap colors for whiteflies and leafhoppers (Fig. 2B) had either very low reflectance at all wavelengths (e.g., black and dark green trap bases) or had moderately high reflectance in the blue (400–480 nm, e.g., true blue trap base) or red regions of the spectrum (600–700 nm, e.g., red trap base).

Discussion

The spectral reflectance characteristics of the different color trap bases varied greatly. However, the spectral reflectance characteristics of the most attractive base colors (lime green, spring green, and yellow) for *Bemisia* and leafhoppers were moderately high in the 490- to 600-nm spectral range. These results agree with the *Bemisia* phototactic spectral responses reported by El-Helaly et al. (1981) as well as several other authors for *Bemisia* (Lloyd 1921, Mound 1962, Gaum and Giliomee 1994, Blackmer et al. 1995, Hoelmer et al. 1998). Further, in our studies, we found similarities between the spectral reflectance of lime green, spring green, and yellow trap color bases and the spectral characteristics of the underleaf surfaces of cotton leaves. As cotton becomes nutrient stressed, the green/yellow-green peak tends to become amplified slightly as compared with the red peak (data not shown) although it never becomes as exaggerated as that observed in the traps with lime green and spring green trap bases. The results suggest that leaf color and plant nutrition that affects leaf color may play a role in *Bemisia* host recognition and selection.

Our results show that numbers of adult *B. argentifolii* and thrips caught per trap per day were significantly higher in traps with lime green and yellow, and true blue and white color bases, respectively, compared traps with red, rum, spring green, dark green, or black color bases. It appears that whiteflies and thrips can distinguish between the nine tested colors even when the colors are in close proximity (7 cm) to each other. The relative differences between trap catches in traps with the eight different color bases were similar in choice and no-choice tests.

During the growing season, cotton attracts more silverleaf whiteflies compared with alfalfa (Chu et al. 1995, Yee et al. 1997). Our trap results in cotton and alfalfa plots reflected these differences in population sizes.

In the case of western flower thrips, the color true blue with a high spectral reflectance between 400 and 480 nm appeared most attractive to adults. These results agree with those of other authors (Brodsgaard 1993). Thrips catches were low in cotton because peak abundance occurs earlier in the cotton season (March and April) as opposed to the time of our studies (August to September). White sticky card traps have also been reported to attract more western flower thrips compared with other color sticky traps (Yudin et al. 1987, Brodsgaard 1993) probably because white is also high in spectral reflectance below 500 nm. In contrast to these reports, Cho et al. (1995) reported that yellow sticky traps caught significantly more western flower thrips compared with white and blue sticky traps in a staked tomato field study. Matteson and Terry (1992) reported highly significant preference of western flower thrips with increased brightness in the blue-violet spectral range, but no significant preference with brightness in the visible, green-yellow, or UV spectral range was observed. Our results are the first report of *T. palmi* attraction to traps with white color bases. In view of the attraction of western flower thrips to blue bases, additional studies should be undertaken to determine the attractant potential of the color blue to *T. palmi* because its economic importance and the need for sampling techniques.

CC traps with appropriate bases appear to be fairly selective for target insects we have studied. Traps are easy to use, rapidly serviced, and inexpensive to make (Chu and Henneberry 1998). Lime green or yellow appear to be most attractive for *Bemisia;* blue or white for thrips; and yellow, spring green and lime green for leafhoppers. To increase the sensitivity of CC traps at low whitefly density, modifications have been made to increase trap catches by 50% in a greenhouse study (unpublished data). The color selectivity and spectral reflectance data we report here could be useful for tailor making traps specific for certain insects.

Acknowledgments

We thank Marcus Boykin, Patrick Alexander and Mark Madden for their assistance in field trap studies at Brawley, CA in 1996 and 1997, and at Maricopa, AZ, in 1999 respectively.

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Received for publication 6 October 1999; accepted 10 May 2000.